Light Emission from Electron Beam Sustained Discharges ◇

T. Ottenthal , R. Hilbig [a], R. Krücken , A. Morozov , A. Ulrich , and G. Zvereva [b]
[a] Philips Technologie GmbH, Weisshausstr.2 52066 Aachen, Germany
[b] Vavilov State Optical Institute, 199034 St. Petersburg, Russia

The high efficiency of electron beam pumped vacuum ultraviolet light sources [1] motivated a feasibilty-study for using electron beam excitation of dense gases for lighting devices in the visible and near ultraviolet spectral range. When rare gases are used as the light emitting material there is, however, an unfavourable quantum efficiency for the emission of visible light which cannot be overcome. Populating upper levels of optical transitions in the visible (1.55 to 3.1 eV Photons) requires e.g. in neon an excitation energy of more than 18.6 eV. Since the lower levels of the optical transitions are partly metastable there might be the possibility to pump the excited atoms back into higher lying levels before they return to the ground state. The time scale in which the atoms remain excited is on the order of 5 μs. With a typical electron beam flux on the order of $2.5 \times 10^{14}/cm^2s$ in our experimental systems, the probability of reexcitation by the electron beam itself is negligible (10^{-4} of the probabiltiy of excitation from the ground state). Reexcitation may however be accomplished via the free electrons which are produced in the rare gas targets at atmospheric pressure with densities on the order of $10^{12}/cm^3$ by the electron beam excitation. For that purpose the electrons must have kinetic energies on the order of 2-3 eV, the energy difference of the visible transitions.

Experimentally we try to accelerate the free electrons in the electric field of an rf discharge. Modelling of the electron energy distribution function for our experimental conditions is presently being performed in the context of the ISTC project No. 3098. The setup of the table-top electron beam sustained discharges which have been used for the experiments is shown in Fig. 1.

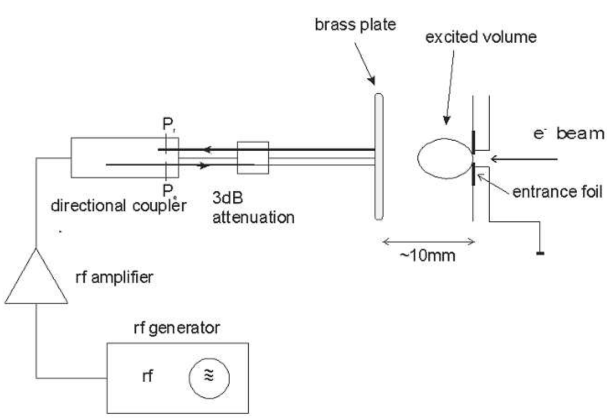
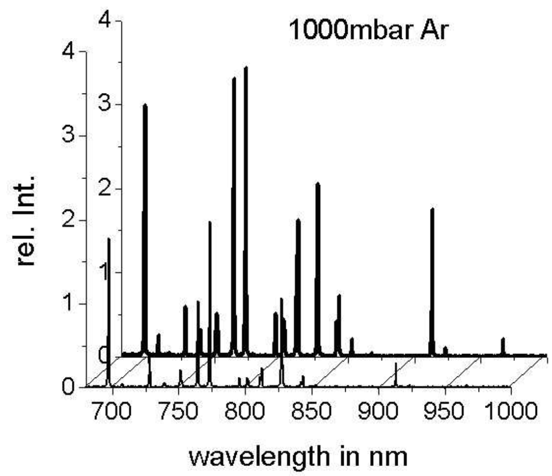


Fig. 1: Experimental setup. A 12 keV electron beam is sent through a 300 nm SiNx foil into the target gas. RF power is capacitively coupled into the gas. The rf power is measured with the directional coupler.

It can be used with continuous as well as pulsed electron beams. Experiments described here were so far performed using fully continuous beams. The system was always operated with gas pressures and rf-fields where there is no rf-discharge operation without the sustaining e-beam. The effect on the light emission from electron beam excietd rare gases when an rf-field is added is described below.

Both the light intensity of spectral lines and of the excimer bands is altered and a broad-band emission appears when the rf-field is switched on. A (f=30 cm) VUV spectrometer (McPherson 218) and a small fiber optics spectrometer were used for optical diagnostics in the VUV and visible range, resepctively.



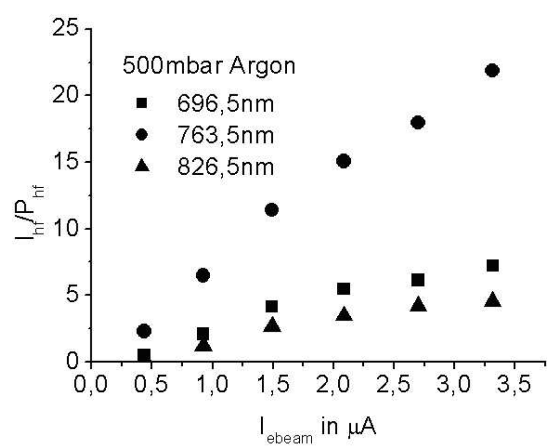


Fig. 2: Electron beam induced emission spectra from argon with and without rf-power applied (top, back shifted spectrum and front spectrum, respectively). The intensity of three argon-I lines normalized to the rf-power which is applied is shown versus electron beam current (below). The intensity of the lines without rf excitation was subtracted prior to normalization.

Electron beam excited rare gas targets emit np-ns (n=3 to 6 for Ne to Xe) transitions in the visible and near infrared spectral range. It was observed that these spectral

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lines show an increased intensity when rf fields are coupled into the gas. The effect is demonstrated in Fig. 2(top) for the case of argon (an exception is found for HeI lines in the visible which show as slight decrease in intensity). An indication that the increase in intensity is due to the "back- pumping" effect described above is shown in Fig. 2(bottom): Variation of the electron beam current leads to a variation of the line intensity caused by the rf field. To exclude that the variation is just due to the variation of rf power deposited in the gas the intensity values are derived by subtracting the intensity produced by the electron beam, alone, and then normalized to the rf- power applied to the gas. The linear increase of the data normalized in this way can be interpreted as an increase in the density of metastable Ar atoms with increasing electron beam power. Starting from these metastable levels a given rf-power can drive transitions for example between the 4p to 4s levels of argon.

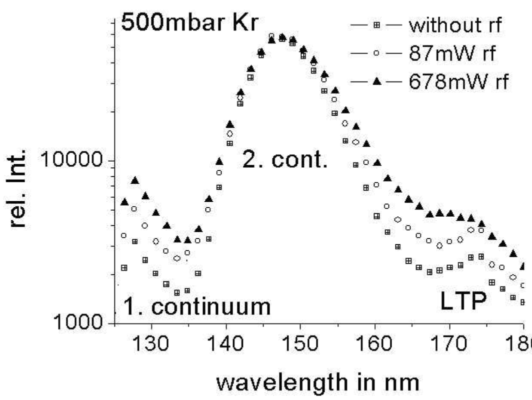
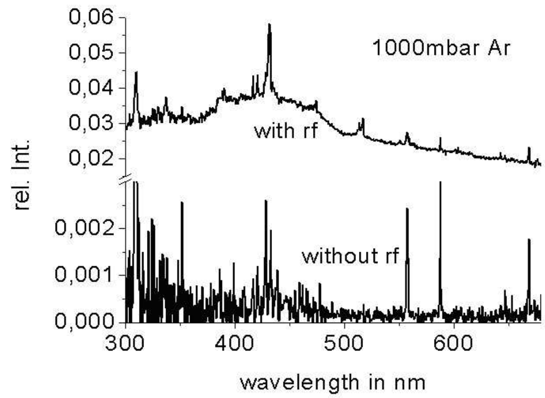


Fig. 3: VUV part of the emission spectrum of 500 mbar krypton for two rf-power values in comparison with a spectrum emitted without rf excitation. The spectra are normalized to the peak intensity of the second continuum (see text).

The modification of the emission spectrum in the vacuum ultraviolet caused by the rf-power is demonstrated in Fig. 3 for Kr at a pressure of 500 mbar. The spectra show the first and second rare-gas excimer continua and the so called classical left turing point emission. The second continuum is due to the transition of vibrationally relaxed excimer molecules whereas both the first continuum and the left turning point emissions are due to transitions from vibrationally high lying levels of the excimer molecules. The spectra are normalized to the peak of the second continuum. The relative intensity increase of the emission which is due to high lying levels indicates either a net heating of the gas [2,3] or a collisional excitation from relaxed to excited vibrational levels by the rf-field driven electrons in the gas similar to the mechanism described above in the context of line radiation. Note, that the peak intensity of the second continuum is reduced with increasing rf-power on an absolute scale.



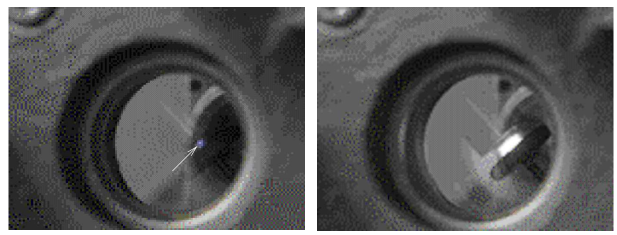


Fig. 4: The appearnce of a broad-band visible emission is demonstrated by a photograph of the system with pure electron beam excitation (20 mW electron beam power, left, marked with an arrow) and additionally 667 mW rf-power, respectively. The corrsponding emission spectra are shown above.

The third observation in the electron beam sustained discharges described here is the appearance of a broad continuum in the visible range of the spectrum. Visually it is the most prominent effect. Based on a comparison with spectra described for pure rf-discharges [4] we attribute this emssion to Bremsstrahlung. This Bremsstrahlung is produced in collisons of the free electrons with neutral gas atoms. The spectrum and the visual appearance of the light source is shown in Fig. 4. The efficiency of this light producing mechanism is on the order of 0.1%.

References

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